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# PLANT AND AIR TEMPERATURES IN DIFFERENTIALLY-IRRIGATED CORN*

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## ABSTRACT

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Studies by Jackson et al. (1977) and Idso et al. (1977) indicate that wheat is not stre for water unless leaf temperature exceeds air temperature. One objective of the study ported here was to determine relationships between leaf temperature and air tempera within corn canopies as a function of water stress. A second objective was to evaluate effects of varying levels of plant water stress on crop temperature. A third objective to establish the relationship between plant water stress and crop temperature in corn ( *mays* L.) with the aim of providing practical water resource management tools.

Meteorological, physiological and phenological measurements were made in nine p of corn, grown on Valentine fine sand (Typic ustipsamment) at the Sandhills Agricult Laboratory located near Tryon, Nebraska. Each plot received one of seven different gation treatments. Canopy temperatures were measured with an infrared thermomete midday throughout the growing season. Air and leaf temperature measurements were m on an hourly basis with thermocouples. Physiological and phenological observations w made weekly.

The average midday difference in canopy temperature between stressed and non-stres areas was as large as 7.0°C. In fully-irrigated plots, the standard deviation of midday c opy temperature was about 0.3°C but in non-irrigated areas it reached, at times, 4.2°C is concluded that a standard deviation of temperature in a plot exceeding 0.3°C sig that some plants are experiencing water stress. This behaviour can indicate the need irrigation.

Daily profiles of leaf and air temperature in stressed and non-stressed canopies w found to be similar. Profiles tended to be lapse before crop cover was complete and verted later in the season. At any level within the stressed canopy, plants were war than at the same level within the non-stressed canopy. The midday temperature of su leaves of non-stressed and moderately stressed plants was generally 1—2°C below air t perature. The temperature of sunlit leaves in severely stressed plants was as much as 4. above air temperature. It was observed that corn plants may be subject to water stress still be cooler than air temperature.

## INTRODUCTION

Leaves of moisture stressed plants have been found to be warmer th those of non-stressed plants. Temperature differences between stressed a

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stressed leaves reported for various crops range from +2 to +8°C (Miller, 3; Eaton, 1929; Millar et al., 1971; Ehrler et al., 1978).

iegand and Namken (1966) found that the difference in temperature veen stressed and non-stressed cotton (*Gossypium hirsutum* L.) leaves ed from 2.5 to 4.5°C when solar radiation flux density was 200 W $m^{-2}$ 1100 W $m^{-2}$, respectively.

anner (1963) suggested that the temperature difference between stressed non-stressed potato (*Solanum tuberosum* L.) leaves gives a qualitative in- tion of the differences in transpiration. He concluded that with a better erstanding of heat and vapor transfer processes at the plant surface, leaf perature measurements may provide quantitative data on plant water ıs.

hrler (1973) stated that long-term measurements of leaf temperature pro- an indirect indication of stomatal behavior. Ehrler et al. (1978) demon- ted that canopy temperature in wheat increased as plant water potential de- sed. Differences in canopy temperature between stressed and non-stressed at plants were shown to be a reliable indicator of plant water status.

lark and Hiler (1973) found that stomatal resistance in peas (*Vigna nsis* L.) increased as moisture stress developed, resulting in increased leaf perature. They concluded that the status of water in plants represents an gration of the atmospheric demand, soil-water potential, rooting density distribution and other plant characteristics, as well. Thus, for a true sure of plant water deficit, measurements should be made on the plant ead of in the soil or the atmosphere.

ston and Van Bavel (1972) and Nixon et al. (1972) suggest that a large ability in canopy temperature should signal the onset of water deficits to the inhomogeneous soil moisture retention properties in large fields. ler (1973) and Ehrler et al. (1978) showed that the differential in leaf— temperature can be used to signal the need for irrigation. Ritchie (1977) gested using the temperature difference between stressed and non-stressed ts to detect the occurrence of soil water deficits.

n view of the above-stated findings a study was designed with the follow- objectives: (1) to evaluate the effects of varying levels of plant water ss on crop temperatures; (2) to establish the relationship between plant er stress and crop temperature in corn with the aim of providing practical er resource management tools (e.g. irrigation scheduling, drought surveil- e); and (3) to determine the relationships between leaf temperature and temperature within corn canopies as a function of water stress.

THODS AND MATERIALS

he study was conducted at the University of Nebraska Sandhills Agricul- l Laboratory, located near Tryon, Nebraska (41°47′N; 100°50′W; 975 m ve m.s.l.). Details of the experimental site and research procedures are n in Blad et al. (1981a).

TABLE I

The seven irrigation treatments used for the study

| Treatment | Growth stage | | |
|---|---|---|---|
| | Vegetative | Pollination | Grain filling |
| 1 | G | I | I |
| 2 | I | G | I |
| 3 | I | I | G |
| 4 | G | I | G |
| 5 | I | G | G |
| 6 | G | G | G |
| 7 | G | G | I |

(I) all rows in a plot received a full irrigation during that growth period. (G) an irrigati gradient was established so that one side of the plots received 100% of its water nee while the opposite side received essentially one of its needs.

Seven irrigation treatments (Table I) based upon combinations of tv basic irrigation procedures were imposed on plots of corn (*Zea mays* L. c Pioneer 3780) planted in 0.75 m rows (the plots were 24 rows wide). Fu irrigation (I) consisted of resupplying by irrigation 100% of the water us to all rows in a plot. The amount of water to be supplied through irrigatio was determined by measuring soil moisture depletion with a neutron prob Gradient irrigation (G) consisted of applying full irrigation to row 1 of a pl and applying progressively less water to each succeeding row, until rows 2 through 24 received essentially no irrigation.

Canopy temperatures were measured daily with an infrared thermomet (IRT) between 1200 and 1330 solar time on rows 2, 6, 10, 14, 18 and 22 each plot. Readings began on June 1 and continued throughout the growi season, except for a few days when measurement was not possible. Tw infrared thermometers were used. A Telatemp model 44 was used betwe June 13 and July 17. A Barnes model PRT5 was used for the remainder the season. The area viewed by the IRTs was calculated to be about 2 r (2 m × 0.95 m). The viewing angle decreased from about 22 to about 1 degrees from the horizontal as the crop increased in height.

In one plot (hereafter, called the instrumented plot), air and leaf temper tures were measured at three different levels within the canopy in rows 2, 10, 14, 18 and 22. The bottom, middle and top of the canopy were des nated as levels 1, 2 and 3, respectively. The thermocouples in levels 2 and were raised as the crop grew. The crop reached its full height by July 26 ar no further adjustments in instrument height were made after that date.

Leaf temperatures were measured at each level with a set of 5 or 6 evanohr constantan thermocouples (0.13 mm diameter) which were wired in paralle The junctions of each thermocouple were distributed among a number different leaves. They were taped to the lower surfaces using the metho described by Blad et al. (1981b).

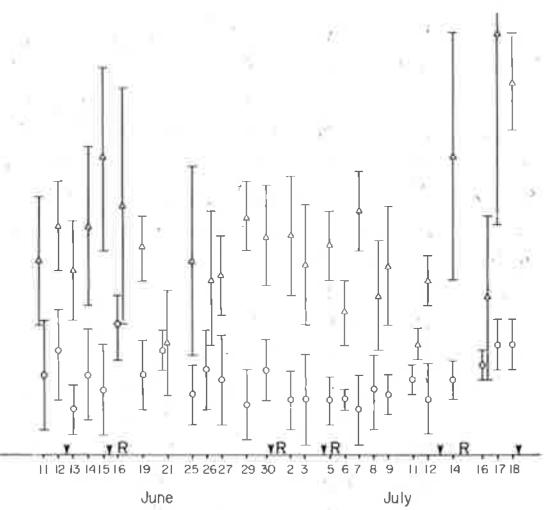
opper-constantan air thermocouples, embedded in 6 mm diameter teflon 's to dampen rapid fluctuations in air temperature, were placed at level )ne air thermocouple was also mounted permanently in row 2 at a height 3 m above ground. Air thermocouples were radiation shielded with a ar-covered shield 80 mm in diameter.

ULTS AND DISCUSSION

*perature differences between stressed and non-stressed areas*

he average midday IRT-measured temperature difference between row and row 2 (notated as $^*T_{22} = T_{22} - T_2$) was larger on gradient (G) plots on fully irrigated (I) plots during the vegetative (Fig. 1), the pollination . 2) and the grain-filling (Fig. 3) periods.

he standard deviation of $^*T_{22}$ (designated $\sigma_T$), which represents the day spatial variability in canopy temperature, averaged 1.0°C on I plots 1.2°C on G plots prior to mid-July when nearly full plant cover was eved. Thereafter $\sigma_T$ decreased to 0.3°C on I plots but remained about C on G plots (Table II), though on some days $\sigma_T$ on G plots was as t as 4.2°C. The large temperature variability in the G plots results n microscale variations in soil water retention characteristics and from erences in the amount of irrigation applied to row 22 during various vth stages. In some G plots row 22 was fully irrigated during a previous vth period but in other plots it received no irrigation. On several days




1. The average difference in midday canopy temperature between row 22 (stressed, gles) and row 2 (non-stressed, circles) on plots receiving a gradient treatment and in -irrigated plots during vegetative growth. Standard deviation of each data point is in- ted with a bar. The occurrence of rainfall is indicated with an R and irrigations are cated with arrows.

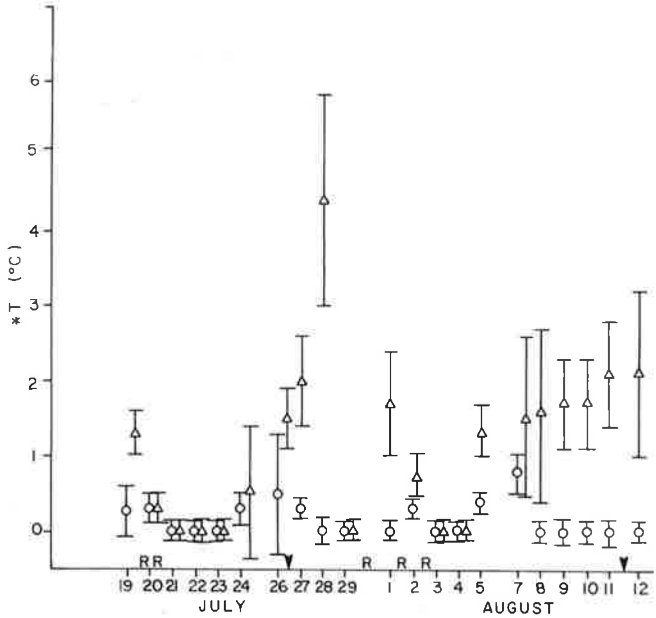



**Fig. 2.** As Fig. 1 but for the pollination period.

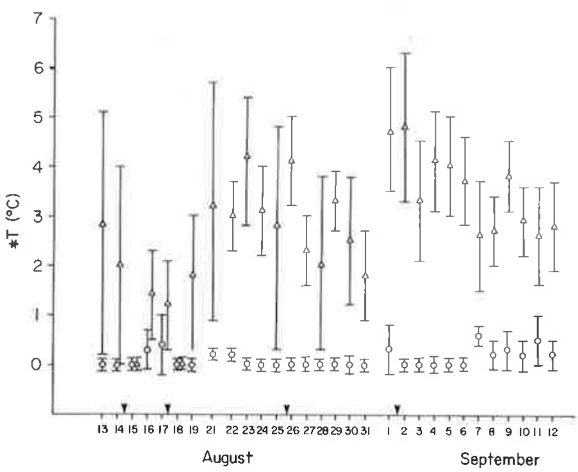



**Fig. 3.** As Fig. 1 but for the grain-filling period. The low *T and $\sigma_T$ value for the stre
plots on August 18 was due to cool overcast weather.

during the pollination period $\sigma_T$ was small because of cool, cloudy and
weather.

Rainfall or irrigation caused minor reductions in $\sigma_T$ during much of the v
etative period. During the late vegetative, pollination and grain-filling perio
$\sigma_T$ on well-irrigated plots increased prior to irrigation and showed a signific
reduction after irrigation on July 13, July 26, August 17 and September 1

E II

erage midday temperature differences between row 22 and row 2 ($^*T_{22}$) for the nt growth stages of fully-irrigated (I) and gradient (G) plots. (The standard devi-f $^*T_{22}$ ($\sigma_T$) is also given. $^*T_{22}$ and $\sigma_T$ were computed using data for all days and sing clear-day data only)

| f | I Plots | | G Plots | |
|---|---|---|---|---|
| | $^*T_{22} \pm\sigma_T$ (All daily values) | $^*T_{22} \pm\sigma_T$ (Clear days only) | $^*T_{22} \pm\sigma_T$ (All daily values) | $^*T_{22} \pm\sigma_T$ (Clear days only) |
| tive | 0.4 ±0.8 | 0.2 ±1.0 | 2.9 ±1.3 | 2.7 ±1.2 |
| tion | 0.2 ±0.3 | 0.2 ±0.3 | 1.2 ±1.1 | 1.8 ±1.0 |
| illing | 0.1 ±0.2 | 0.2 ±0.3 | 2.8 ±1.2 | 3.1 ±1.1 |

the oblique IRT viewing angles used in this study, values of $\sigma_T$ above occurred when some plants began to experience water stress. This re-ompares favorably with the findings of Heermann and Duke (1978) found that $\sigma_T$ was about 0.2°C in well-irrigated corn when the IRT was t oblique viewing angles. At vertical viewing angles they observed that s approximately 1.5°C.

the basis of these findings, it appears that the irrigations on July 13, 26 and August 17 were one or two days too late to prevent stress in the vatered plots. The irrigation of September 1 was timely — applied as it n the evening of the day on which stress was first observed. The irri-s of August 11, 14 and 25 were made prior to the appearance of plant

gations were scheduled with the aid of the neutron probe. That method ally gave satisfactory results. These findings suggest the possibility of crop temperature and $\sigma_T$ measurements to evaluate and compare the iveness of various methods for scheduling irrigation and for evaluating niformity of irrigation applications made with different systems and iques. The use of $\sigma_T$ to schedule irrigations also offers possibilities. $\sigma_T$ increases above the average expected value, 0.3°C in this study, the for irrigation is indicated.

*temperature as an indicator of severity of stress*

fferences in temperature between stressed and non-stressed crops did egin to develop until after 1100 solar time. However, on September 1 e instrumented plot, $^*T_{22}$ was 1.5°C at 0800 and 3.5°C at 0900 h, indi-g that stomata were already closing on the plants in row 22. This re-an increase in the severity of water stress experienced by the plants, suggests that the timing of crop temperature measurements may also sed to distinguish the degree to which plants are stressed for water. arch to verify this hypothesis is now underway at our laboratory.

*Daily patterns of leaf and air temperature*

Before crop cover was complete, the vertical leaf temperature profiles the instrumented plot tended to lapse in both stressed and non-stressed are during the day. After crop cover was complete, the vertical leaf temperatu profiles during the day were generally inverted. This was primarily due to t absorption of solar radiation by leaves near the top of the canopy, and t shading of leaves within the canopy. Differences in leaf temperatures corresponding levels also increased across the plot because of reduced tra spiration in the water stressed plants.

A typical daily pattern of thermocouple-measured leaf and infrare measured canopy temperatures under conditions of clear skies with mod ately strong winds, is given in Fig. 4. Canopy temperatures measured wi the IRT closely followed the temperature of sunlit leaves in both the stress and non-stressed areas (row 22 and row 2, respectively).

The vertical air temperature gradients (Fig. 5) in the non-stressed row (2 followed the same pattern as the leaf temperature gradients, that is, bo were inverted. However, in the more open canopy in the stressed row (22 there was sufficient mixing to cause the air temperature profile to be near isothermal even though the leaf temperature gradient was inverted.

As transpiration rates decrease, leaf temperatures increase (Hsiao, 197 and the proportion of absorbed radiant energy converted to sensible he increases. This causes the air in stressed areas to be warmer than in no stressed areas. Thus, data on air temperature differences between stress

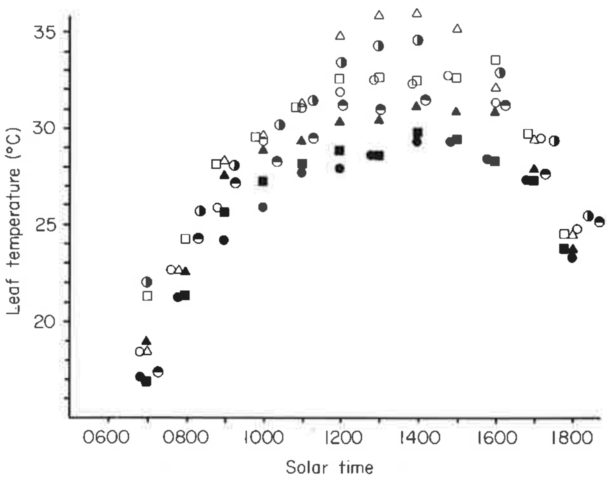
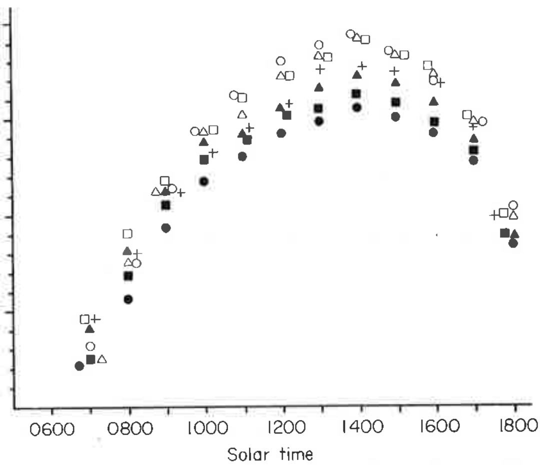
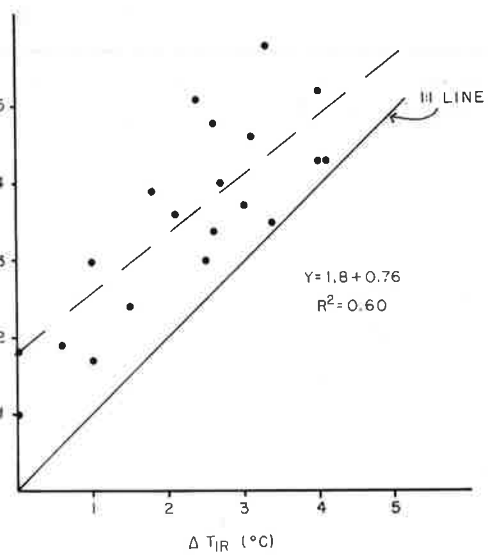



Fig. 4. Daily pattern of leaf temperatures on August 22, 1978, in row 2 (non-stresse and row 22 (stressed) at the bottom of the canopy, middle of the canopy and at the t of the canopy. (Row 2: canopy top, ▲; mid-canopy, ■; canopy bottom, ●. Row 22: ca opy top, △; mid-canopy, □; canopy bottom, ○. $T_{IR}$ row 22, ◑; $T_{IR}$ row 2, ◒.) Infrared ca opy temperatures ($T_{IR}$) are also plotted.




5. Daily pattern of air temperature ($T_A$) on August 22, 1978, in row 2 and row 22 at ottom of the canopy, the middle of the canopy and at the top of the canopy. (Row nopy top, ▲; mid-canopy, ■; canopy bottom, ●. Row 22: canopy top, △; mid-canopy, nopy bottom, ○.) Air temperature at three meters above the soil surface in row 2 is ded (+).




6. Midday air temperature differences ($\Delta T_A$) between the top of canopy of row 22 ssed) and row 2 (non-stressed) in plot 22 and midday canopy temperature differences $_{IR}$) of the same two rows. Data are from August 8—September 4, 1978.

non-stressed canopies, could be suggestive of leaf temperature differ-es. This possibility was investigated by comparing upper level midday temperature differences with the midday infrared canopy temperature erences on 20 days between August 8 and September 4 (Fig. 6). Air temperature differences tended to be slightly larger than canopy temperat differences.

It was observed that leaf temperatures tended to fluctuate rapidly but temperatures did not. This may account for much of the observed scat seen in Fig. 6. Thus, canopy air temperature differences may be the m stable indicator of plant moisture stress than instantaneous measureme of leaf temperature, especially under variable climatic conditions.

*Leaf and air temperature differences*

One common index of plant moisture status is the difference ($\Delta T$) in m day leaf temperature ($T_L$) and air temperature ($T_A$) where $\Delta T = T_L - T$ Jackson et al. (1977) have shown that the value of $\Delta T$ obtained at midda partly dependent on the location at which air temperature ($T_A$) is measur Accordingly, we computed $\Delta T$ of leaves at the top of the canopy in rows 10, 14 and 22 using the temperature of the adjacent air ($T_j$) in each row the temperature of the air at 3 m ($T_3$) above the soil surface in row 2 (Fig. Thus, $\Delta T_j = T_L - T_j$ and $\Delta T_3 = T_L - T_3$.

$\Delta T_j$ values did not always follow the leaf temperature differences acr the plot (see the July 25—September 5 data in Fig. 7) but $\Delta T_3$ values d The failure of the $\Delta T_j$ to follow leaf temperature difference is a result of increase in the temperature of the air adjacent to the warmer leaves. Hen it may be difficult to compare $\Delta T$ measurements between stressed and n stressed areas without using a common reference air temperature.

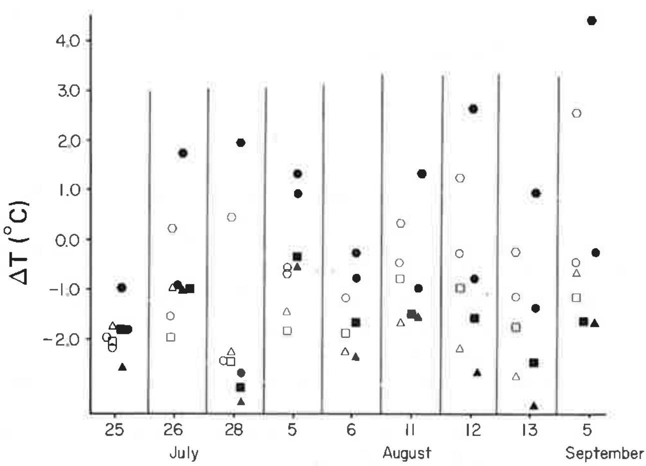



Fig. 7. Midday differences between leaf temperatures at the top of the canopy ($T_L$) a adjacent air temperature ($T_j$, open symbols). Differences also were computed using temperature from three meters above the ground in row 2 ($T_3$, closed symbols). (Row △, ▲: row 10; □, ■: row 14; ○, ●: row 22; ○ , ●.) Calculations were performed on data fr rows 2, 10, 14 and 22 on plot 22 for nine clear days between July 25 and Septembe 1978.

ackson et al. (1977) found that in a plant with adequate water supply $\Delta T$ be near zero or negative, but if it is water stressed $\Delta T$ will be greater n zero. Although this finding was verified by Jackson et al. for wheat, we not find it true in our study with corn. We found instead, that while the n plants in rows 10 and 14 were warmer than the plants in row 2, and s under stress, $\Delta T$ in those two rows remained negative. Only in row 22 ; $\Delta T$ found to be positive. We also observed that yields were reduced in portion to the degree of stress experienced by the plants in rows 10 and This suggests that corn is probably more sensitive to water stress than is eat, and that the use of $\Delta T$ values to indicate water stress may well be soil, p and climate specific.

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